

NBS REPORT

8788

FIRST QUARTERLY PROGRESS REPORT ON  
CRYOGENIC DATA CENTER ACTIVITIES  
FOR THE PERIOD ENDING MARCH 31, 1965



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\* NBS Group, Joint Institute for Laboratory Astrophysics at the University of Colorado.

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# NATIONAL BUREAU OF STANDARDS REPORT

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March 31, 1965

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V. J. Johnson  
R. B. Stewart  
N. A. Olien

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U.S. DEPARTMENT OF COMMERCE  
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## NOTICE

The report on NBS Project 3150420 (see Section 3.0) was prepared under NASA Order R-45, entitled, "Investigations and Studies of Liquid Hydrogen and Other Cryogenic Fluids", for the Office of Research Grants and Contracts of the National Aeronautics and Space Administration. The work is administered under the technical direction of the Space Nuclear Propulsion Office, Lewis Research Center, with Dr. Landon Nichols as project manager

The report on NBS Project 3150422 (see Section 5.0) was prepared under Government Order H-76797, entitled, "Cryogenic Propellant Fluid Properties Data Evaluation Program", for the George C. Marshall Space Flight Center of the National Aeronautics and Space Administration. The work is administered under the technical direction of the Propulsion and Vehicle Engineering Laboratory, Materials Division of the George C. Marshall Space Flight Center with Mr. Harold Perkins, R-P&VE-MCA, contracting officer's technical representative acting as project manager.

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## ABSTRACT

This first quarterly report on activities of the Cryogenic Data Center gives a description of each of the Center's principal functions and projects in addition to the progress that was made during the reporting period. The Documentation Unit issued thirteen weekly lists containing a total of 1123 items of current literature of cryogenic interest. A total of 1858 documents were procured in either full size copy or microform. There were 1612 new entries made into the storage and retrieval system; of these, 1489 were coded in depth for mechanized retrieval. The system had 26,099 accessions at the end of the reporting period of which 11,069 were for properties of materials. Fourteen bibliographies were prepared containing an average of 130 items. The Center received and filled 549 orders for a total of 2733 NBS-CD Documents. The Data Compilation Unit's activities cover work on the thermodynamic properties of argon, hydrogen, oxygen, physical equilibria of binary mixtures, and the dielectric constant of cryogenic fluids. Progress made by the NBS Statistical Physics Section in the quantum mechanical calculation of the second virial coefficient for hydrogen is briefly described. Also included is a summary of work done by the Thermophysical Properties Research Center at Purdue University on a sub-contract for data on eight structural metals and alloys. A listing of all tasks undertaken or planned is given. A list of NBS charts and publications relative to this work is also included.

FIRST QUARTERLY PROGRESS REPORT ON CRYOGENIC DATA CENTER ACTIVITIES  
FOR THE PERIOD ENDING MARCH 13, 1965

V. J. Johnson, R. B. Stewart, N. A. Olien

1.0 INTRODUCTION

In this first quarterly report on activities of the Cryogenic Data Center there is included a description of each of the Center's principal functions and projects in addition to the progress that was made during the reporting period. The Data Center's activities are managed in two principal units; the Documentation Unit under the direction of Neil Olien (NBS Extension 3834) and the Data Compilation Unit under the direction of R. B. Stewart (NBS Extension 3528). The Documentation Unit's basic operation and development is supported from the Bureau's direct appropriation under Project 3150121. Some of the services are reimbursable from other projects and outside sales. The Data Compilation Unit is currently working under the sponsorship of the National Aeronautics and Space Administration for two projects (3150420 and 3150422) and in participation with the National Standard Reference Data System (Project 3150421).

The Documentation Unit's principal activities are: a) to maintain an awareness of current publications and reprints of cryogenic interest, b) to acquire and catalog such literature as needed by the Data Compilation Unit, other laboratory staff, and for completing the Data Center's files, c) to code the pertinent literature in depth for storage and retrieval, and d) to develop and operate a mechanized bibliographic and indexing service for the comprehensive retrieval of information and data in specific subject areas as needed. This Unit also handles the distribution of all the Cryogenic Division's publications (reprints, reports, charts, etc.) and announces the availability of new material periodically.

The Data Compilation Unit is engaged in the critical evaluation of thermophysical property data from the scientific literature for materials at cryogenic temperatures. The objective is the compilation of extensive tables of property values over wide ranges of temperature and pressure. This Unit is a participant in the National Standard Reference Data System which was established in the NBS Institute for Basic Standards in 1963. The Data Compilation Unit is recognized as a national authority for data on the properties of materials at cryogenic temperatures and as a primary project for the entry of such data into the national system. On undertaking a task for data compilation, a bibliography is prepared by the Cryogenic Data Center's Documentation Unit. A systematic and comprehensive search of the abstract journals on the subject is then made and appropriate items added to the bibliography. Copies of all documents in the bibliography are procured which are in turn searched for additional references related to the subject. Following the compilation of the bibliography, the numerical data and pertinent facts related to it are extracted from the literature and compiled on data sheets which are assembled in task notebooks. Related data are then compared and evaluated on appropriate statistical and theoretical bases. Using the "best values" of the experimental data, and appropriate theoretical and empirical techniques, comprehensive data tables over extended ranges of temperature and pressure are compiled. The task is concluded by the publication of a document which describes the data evaluation procedures, and the methods used

in generating data tables; also included are comprehensive data tables together with appropriate graphical representations. In addition to the final publication, various interim reports and documents may be issued. These interim documents include bibliographies resulting from the literature search, compilations of the data extracted from the literature which may be prepared from the task notebooks noted above, and interim tables of properties which may be calculated prior to the final analysis and evaluation of the data. The purpose of these interim publications is to make this material available to others at an early date, prior to the completion of the specific tasks.

## 2.0 CRYOGENIC DATA CENTER, DOCUMENTATION UNIT (NBS PROJECT 3150121)

Progress is reported on the following areas of documentation activity: current awareness service, literature acquisition, descriptive cataloging of documents, indexing and coding of document content, mechanized storage and retrieval of selected information, preparation of bibliographies, and announcement and distribution of NBS-Cryogenic Division documents.

### 2.1 Current Awareness Service

A weekly Current Awareness List is circulated to the laboratory staff and others. This service was initiated in March 1964 and lists new literature of interest in the area of cryogenics that has been noted during the week. During this reporting period thirteen lists were prepared containing a total of 1123 items. The lists are currently distributed to 67 laboratory staff members and 65 others outside the laboratory.

### 2.2 Literature Acquisition

Literature is acquired through subscriptions to current periodicals and by ordering specific documents both for entry into the storage and retrieval system and for the laboratory staff. The Documentation Unit now receives 86 journals, abstract bulletins, title announcement bulletins, etc. which are reviewed for pertinent literature. Specific items are ordered in either microform or printed copy. During this reporting period 1089 printed documents and 769 documents in microform were ordered.

### 2.3 Descriptive Cataloging

Standard library practices are utilized in cataloging periodical and report literature. Authority lists are maintained for standard journal abbreviations and corporate report headings. In addition quick reference files of number designations such as the Defense Documentation Center AD numbers, NASA N numbers, patent numbers, etc. are maintained for all pertinent items entered into the Data Center's system. During this reporting period 1612 references were catalogued for entry into the storage and retrieval system.

### 2.4 Coding and Indexing

The storage and retrieval system uses a coordinate index with some features of the traditional hierarchical index. The field of cryogenics has been divided into nine categories, each of which will have its own thesaurus of indexing terms. Six additional items of



characteristic identification (see Section 2.8) are used. Since the volume of literature in the cryogenic field is greater than can be handled by the present staff, only the documents in two of the subject categories, properties of solids (A-2) and properties of fluids (A-3), are fully coded for coordinate indexing and machine retrieval. A thesaurus for category A-6 (cryogenic processes) is nearing completion and substantial work has been done on thesauri for categories A-7 (laboratory equipment and instrumentation) and A-8 (cryogenic equipment). The indexing and coding of literature are done by professional staff members, who understand the subject matter in much greater depth than do technical librarians and information analysts employed in the large national systems. During the reporting period, 1489 documents were coded and indexed for entry into the storage and retrieval system.

## 2.5 Mechanized Storage and Retrieval

The Boulder Laboratories' Central computer facility is used for storing and retrieving the identity of documents containing information and data for cryogenics. The complete catalog citation, characteristic coding of the documents and its contents, and the detailed subject coding is key punched into cards for transfer to magnetic tape. Computer programs have been written to convert the stored information necessary for mechanized retrieval. Numerically coded information is transferred to a search tape for mechanized retrieval. At the present time there are 11,069 references in categories A-2 and A-3 available for search; of these 990 were added during this reporting period. The forthcoming change by the NBS, Boulder Laboratories Central Computation Facility from an IBM 7090 Computer to a CDC 3600 Computer is currently requiring a number of program changes.

## 2.6 Preparation of Bibliographies

Bibliographies in answer to user questions are prepared by searching the magnetic tape for the accession numbers of references which contain the desired information. A flexowriter listing of these references is prepared from individual punched paper tapes containing each citation. The charge for this service is \$12.00 per minute of computer time and \$0.15 for each reference listed. An index to the bibliography is supplied if desired by the customer. A typical search of one or two subject areas requires one to three minutes of computer time. During the reporting period 14 bibliographies were prepared containing an average of 130 items per bibliography.

## 2.7 Announcement and Distribution of Publications

An announcement of publications and services available from the Cryogenic Data Center was mailed to some 3600 persons on the Data Center's mailing list during this reporting period. New announcements are made whenever enough new publications can be listed to warrant the expense of the mailing. Individuals desiring their names on this mailing list may be included by returning one of the registration cards provided on the inside of the back cover of this report. A current list of publications of the Cryogenic Division will be mailed to all new entries on the mailing list. Blanks for ordering copies of NBS Cryogenics Division documents are also provided. Over 500 items of reprints, reports, charts, and data sheets which have evolved from activities of the Cryogenic Laboratory over the past several years are available for sale at a price sufficient to cover cost of printing and handling. During the period of this report 549 orders were filled with 2733 items.

## 2.8 CHARACTERISTIC CODING DESIGNATIONS for CRYOGENIC LITERATURE

### Categories

- A-1: Books, Reviews, Surveys, Bibliographies, Proceedings, etc.
- A-2: Properties of Solids
- A-3: Properties of Fluids
- A-4: Solid State, Theoretical, Phenomena, Basic Physics, etc.
- A-5: Cryogenic Techniques, Tricks, Unique Methods, Unusual Procedures, etc.
- A-6: Cryogenic Processes, Heat Transfer, Purification, Fluid Flow, Liquefaction, Safety Procedures, etc.
- A-7: Laboratory Equipment and Instrumentation
- A-8: Cryogenic Equipment
- A-9: General Interest Literature, News, Management, Programs, Accidents, Miscellaneous

### Language

- B-1: English, B-2 French, B-3 German, B-4 Dutch, B-5 Italian, B-6 Japanese, B-7 Russian, B-8 Spanish, B-9 Other

### Cryogenic Interest

- C-1: Cryogenic Temperature Range (0 to 130°K where not specifically designated in C-4 through C-7 below)
- C-2: Cryogenic Interest but not in Cryogenic Temperature Range (except where designated C-8)
- C-3: Not of Direct Cryogenic Interest
- C-4: Below 1°K
- C-5: 1 to 10°K
- C-6: 10 to 50°K
- C-7: 50 to 130°K
- C-8: 130 to 300°K

### Form of Data (Omitted where not pertinent)

- D-1: Numerical Data Included
- D-2: No Data
- D-3: Graphical Data Only

### Type of Article (Omitted where not pertinent)

- E-1: Experimental, Experimental and Theoretical, Original Work
- E-2: Review Article, Compilation, Correlation, Discussion
- E-3: Theoretical Only, No Specific Data Given

### Availability of Document (suggested source)

- F-1: Cryogenic Engineering Laboratory
- F-2: National Bureau of Standards
- F-3: Office of Technical Services (OTS)
- F-4: U.S. Government Printing Office
- F-5: Armed Forces Technical Information Agency (ASTIA)
- F-6: Technical Libraries Generally (Published Literature)
- F-7: Technical Libraries - Special (Foreign Literature - Special Periodicals)
- F-8: Company Bulletins and Reports (Universities, Research Labs., etc.)
- F-9: Other (Patents, Theses, Translations, etc.)

### Form of Document

- G-1: Published - Open Literature, Journals, etc.
- G-2: Books, Proceedings
- G-3: Company Periodicals (includes University, Foreign Gov't, State Institutions, etc.)
- G-4: Government Periodicals (U.S.)
- G-5: Company Reports, Private, Public, Gov't Contract (includes Foreign Gov't Reports)
- G-6: Government Reports (U.S.)
- G-7: University Theses, Doctoral Dissertations, Master's Theses
- G-8: Patents (U.S. and Foreign)
- G-9: Other (Unpublished, Informal, Preprints, Letters, Notes, Term Papers, Talks, etc.)

### 3.0 CRYOGENIC DATA CENTER, DATA COMPILATION UNIT

#### REPORT ON TASKS UNDER NBS PROJECT 3150420

(NASA-SNPO, NASA ORDER R-45)

Progress is reported on data compilation tasks for the compilation of the saturation and fixed point properties of cryogenic fluids, thermodynamic properties of argon, and the thermodynamic properties of normal and para hydrogen. Special emphasis has been given during the current reporting period to the compilation of differences in properties of ortho and para hydrogen.

#### 3.1 Compilation of Saturation Properties for the Cryogenic Fluids

A bibliography on experimental data of saturation properties of cryogenic fluids has been completed and published as NBS Technical Note 309<sup>18\*</sup>. Copies of this bibliography are available from the Cryogenic Data Center. It contains 507 references to experimental work which are presented for the properties of the cryogenic fluids in the solid, liquid, and vapor phases at saturation. The cryogenic fluids included are helium, hydrogen, neon, nitrogen, oxygen, air, carbon monoxide, fluorine, argon, methane, and isotopes of helium, hydrogen, and methane. Each article has been reviewed and coded for properties, method of presentation of the data, and temperature range. An index lists each fluid in five categories; solid-solid transition, solid-liquid transition, solid-vapor transition, liquid-vapor transition, and triple point. For helium the liquid-liquid transition is also included. Each category is indexed by the properties; pressure-temperature data, density and heat capacities of all phases at saturation, and latent heats.

In previous reports to the sponsor, it was noted that work sheets have been compiled for H<sub>2</sub>, Ne, O<sub>2</sub>, A, N<sub>2</sub>, CO, Air, CH<sub>4</sub>, and the deuteromethanes. These work sheets are a tabulation of all of the experimental data from the literature, together with pertinent comments on these data. Task notebooks of these data are then used by the data analyst in his study and evaluation of the data.

In conjunction with this task a study of vapor pressure equations has also been pursued during the current reporting period. This study has been concerned primarily with the vapor pressure data for oxygen since the experimental data in the literature for oxygen are extensive and quite precise. This study of the vapor pressure of oxygen has been completed and a manuscript prepared as an NBS Report, which is now in press. This work was done in conjunction with NBS Project 3150422, Task No. 1C.

#### 3.2 Thermodynamic Properties of Argon

The task on the thermodynamic properties of argon is assigned to a summer employee who is a Ph.D. candidate during the remainder of the year. As a part of this project, a bibliography of documents containing information on thermophysical properties of argon has been published as NBS Technical Note No. 217<sup>13</sup>. An interim table of thermodynamic properties of argon has also been prepared as a report to sponsor and is printed as NBS Report 8293<sup>14</sup>. Work is continuing on this task to improve the representation of the data by an equation of state, and to include new data that has been published since the NBS Report was prepared. Additional tests and studies of the equation of state and vapor pressure functions are also being conducted to

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\* Superscript numbers refer to references listed in Section 9.0 of this report.

ascertain the accuracy of the equations and to determine the uncertainty of the thermodynamic properties calculated from these functions. This task is also partially supported by NBS Project 3150422. This task has been inactive during the current reporting period.

### 3.3 Thermodynamic Properties of Normal and Para Hydrogen

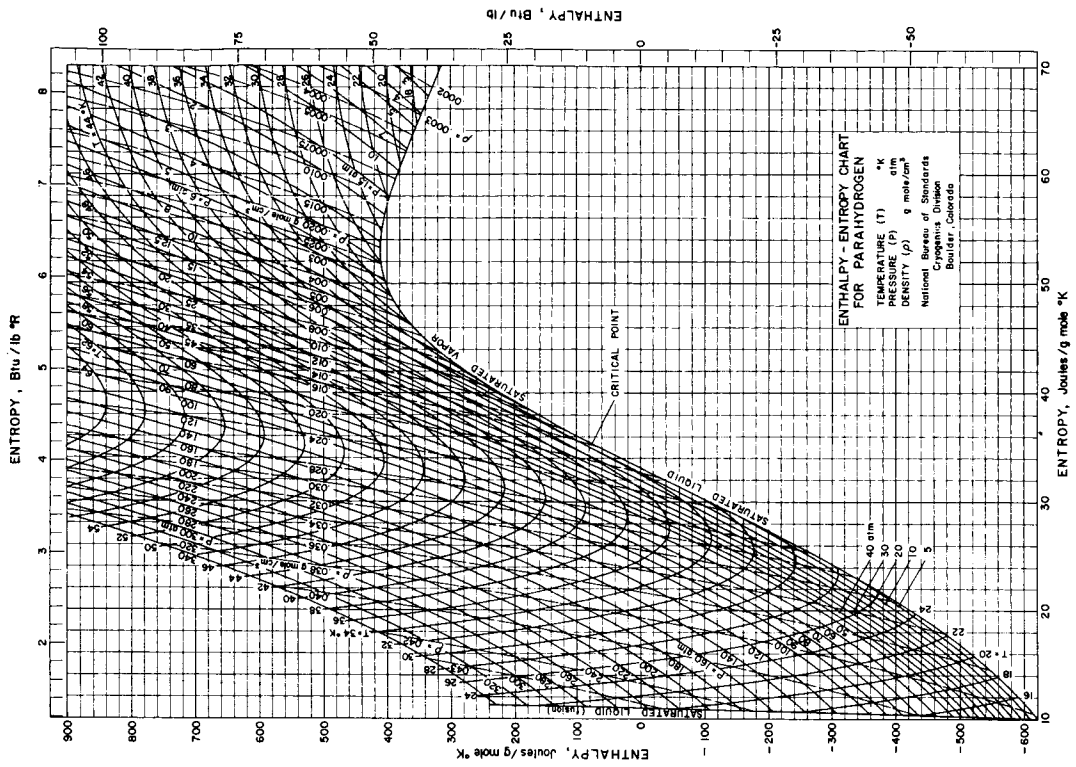
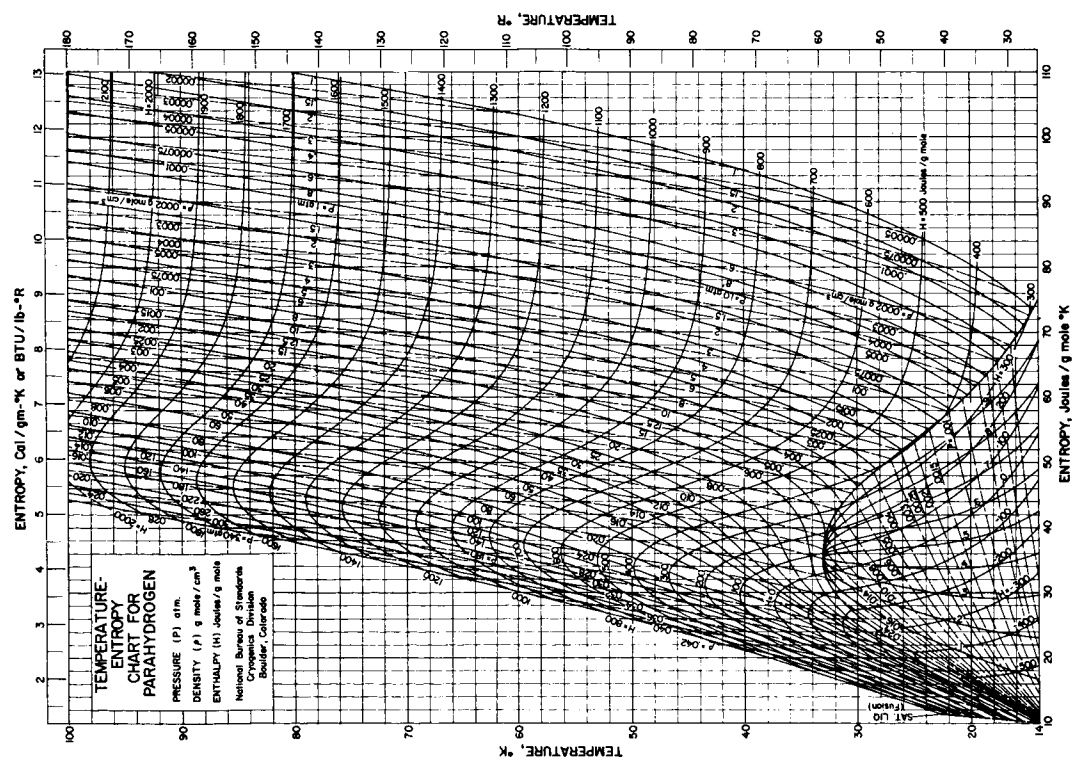
The objective of the task for the compilation of the thermodynamic properties of normal and para hydrogen is a critical evaluation of all of the experimental data on hydrogen available from the world's literature (including the measurements on parahydrogen recently completed in this laboratory). Ortho-para and isotopic modifications over broad ranges of temperature and pressure will be considered. Because of the large amount of very accurate data available for hydrogen, the objective of this task will include an extensive theoretical study of the properties of hydrogen. As an aid in this study, the Statistical Physics Section in the NBS Institute for Basic Standards (221.05) has undertaken the quantum mechanical calculation of second virial coefficients for hydrogen. Progress on this task is reported below (see Section 3.4).

During the current reporting period, two new thermodynamic property charts for para-hydrogen have been completed. These charts were prepared from the new tables of thermodynamic properties in "Thermodynamic and Related Properties of Parahydrogen from the Triple Point to 100°K at Pressures to 340 Atmospheres", by H. M. Roder, L. A. Weber, and R. D. Goodwin, NBS Monograph 94 (1965). The tables were calculated from new measurements in another project under NASA Order R-45. The graphs were constructed under NBS Project 3150420. Reduced copies of the graphs are included in this report.

To accommodate a need for information on the effect of ortho-para composition on hydrogen properties, special attention has been given to the compilation and study of the literature relating differences due to ortho-para composition, during the current reporting period, under NBS Project 3150400. This task will be carried out in two steps, the first will be the compilation of the significant literature and data on the effect of ortho-para composition on hydrogen properties, which will be issued as an NBS Report. This interim report will include a listing of all of the literature references, a tabulation of the numerical data, and a graphical display of the data, for the differences in thermodynamic and transport properties due to ortho-para composition. This compilation will not include an evaluation of the data, however, any pertinent comments on the data will be included. The second step in this task will be the critical evaluation of the data, to determine best values for the thermodynamic and transport property differences due to ortho-para composition. It is intended that extensive tables of tabular data, together with graphical displays of this data, will be provided as a result of this evaluation. In addition a theoretical study will be made as an aid in the extrapolation of this data to ranges of pressure and temperature for which measurements are not available.

### 3.4 Quantum Mechanical Calculations of the Properties of Dilute Hydrogen

As a part of the study of hydrogen properties, the Statistical Physics Section (221.05) has undertaken to calculate quantum mechanically the second virial coefficient for ortho-para hydrogen assuming a spherical potential of the Lennard-Jones type. This is intended as a first step in a larger program which will involve the calculation of the equation of state and transport properties of dilute hydrogen over an extensive temperature range taking into account



quantum mechanical effects. Consideration will then be directed to different forms of the potential to arrive at the best expression for optimal agreement with experimental results. A study of the existing literature on this subject indicates that there are no calculations beyond those done by E. G. D. Cohen, et al., (Physica 22, 791, 1956) which are of very limited extent and accuracy. As a start, therefore, their calculations are being redone using their potential function but extending the temperature range and numerical accuracy of the computation.

In the present reporting period computer programs have been developed for calculating the phase shifts required for computing the second virial coefficients and other properties. This program has now been thoroughly tested and all the necessary phase shifts for this case have been obtained. To the accuracy claimed by Cohen, et al., there is very encouraging agreement between our results and theirs in the region for which they performed their work. The programs for obtaining the second virial coefficient from these phase shifts is currently being developed which will allow for comparisons with those of Cohen, et al.

#### 4.0 REPORT ON TASKS UNDER NBS PROJECT 3150421

(NBS-NATIONAL STANDARD REFERENCE DATA PROGRAM)

Some funding has been received from the NSRDP during the past two years, as a supplement to the other agency funding which provides the main support of this project. This funding is used to supplement the activities on the task for the thermodynamic properties of normal and para hydrogen. The activities on this task are described in Section 3.3.

#### 5.0 REPORT ON TASKS UNDER NBS PROJECT 3150422

(NASA-MSFC, GOVERNMENT ORDER H-76797)

Progress is reported on the data compilation tasks for the thermodynamic properties of oxygen, binary mixtures of oxygen and nitrogen, binary mixtures of argon and nitrogen, and the dielectric constant of oxygen.

##### 5.1 Thermodynamic Properties of Oxygen

The task of the compilation of thermodynamic property data of oxygen was initiated under a previous project. Under this previous project, a bibliography of documents containing information of thermophysical properties of oxygen at low temperatures was published, as NBS Technical Note No. 137<sup>2</sup>. An interim table of thermodynamic property data was also issued as NBS Report 7922<sup>10</sup>. Under this project the evaluation of the oxygen data is continuing, to obtain an improved equation of state for the properties of oxygen and to incorporate new data on the properties of the liquid, which will provide an improved table of data. Particular emphasis is also given to establishing the uncertainty of the oxygen data.

During the current reporting period, an analysis of the vapor pressure data for oxygen with the selection of a functional relationship for the representation of vapor pressure has been completed. This work was done in conjunction with NBS Project 3150420, Task No. 1A. An NBS Report on this work is now in press.

Two new sources of liquid oxygen data have recently been acquired from private communications from the experimenters. The first set of values is from Dr. F. Din of the British Oxygen Co., and the second set represent preliminary results from the measurement program in NBS Section

315.04. These new data, together with the two sets of liquid oxygen data previously published [Van Itterbeek, A., and Verbeke, O., Cryogenics 1, No. 2, 77-80 (1960); and Timrot, D. L., and Borisoglebskii, V. P., Soviet Phys. JETP 11, 1248-50 (1960)] are now being studied. The four sets of data have differences in density of as much as  $1\frac{1}{2}\%$  for isotherms near the critical temperature. A study is currently underway to determine the reasons for the experimental differences, and it is anticipated that corrections may be applied to some of these data which will bring them in closer accord. The preliminary data from Section 315.04 are being used to predict saturated liquid densities, and these new saturation densities have been fitted to a function suggested by Percy Ehrlich at the recent Third Symposium on Thermophysical Properties, sponsored by ASME. Preliminary calculations indicate that this function will be useful for representing the saturated liquid data, and for making some adjustments in the other data sets.

During the next reporting period, the major effort on this project will be a continuation of the evaluation of the oxygen data. It is anticipated that an improved equation of state for oxygen will be determined in the next three months.

## 5.2 Thermodynamic Properties of Argon

This task is jointly funded by NBS Project 3150422 and 3150420. A report on progress for this task is contained in the preceding description of tasks for Project 3150420.

## 5.3 Physical Equilibria and Related Properties of the Binary Mixtures of Oxygen and Nitrogen, and the Binary Mixtures of Argon and Nitrogen

Work has been initiated on this task during the current reporting period. At the present time this activity is concerned with updating the previous bibliographies compiled in the Cryogenics Division, and extracting the data from the literature. This previous bibliography was published as NBS Technical Note No. 56, entitled "A Bibliography of the Physical Equilibria and Related Properties of Some Cryogenic Systems" by Thomas M. Flynn, May 1960. (Copies are available from the Cryogenic Data Center.)

## 5.4 Dielectric Constant Data for the Cryogenic Fluids

The task for compiling the dielectric constant data for cryogenic fluids was initiated in a previous project, which became inactive during April, 1964 with the publication of NBS Report 8252<sup>12</sup>. This compilation presented the result of a search of the world's scientific literature for dielectric constant data for ten cryogenic fluids. All pertinent experimental data are listed in this report without any attempt to evaluate the data, but appropriate comments regarding the experimental methods and reliability are presented.

During the current reporting period, work on this task was resumed to analyze the data for oxygen which was specifically required for NBS Project 3150464. The funding for this dielectric constant work during the current reporting period was shared by NBS Projects 3150420, 3150422, and 3150464. The work accomplished on this task was the critical analysis of the dielectric constant data for oxygen, and the calculation of the table of the dielectric constant values for limited ranges of pressures and temperatures for the liquid. At the present time these values are subject to uncertainties of 0.6% due, in part, to the uncertainties in the liquid density data for oxygen. As soon as more reliable liquid density data are determined from the study reported above under item 5.1, tables of dielectric constant for

oxygen with a reduced uncertainty will be calculated for wide ranges of temperature and pressure and issued as an NBS Report. The analysis of the data for oxygen has now been completed, and this project is again inactive until such time as the above calculation may be carried out.

6.0 THERMOPHYSICAL PROPERTIES RESEARCH CENTER, PURDUE UNIVERSITY, NBS SUB-CONTRACT NO. CST-7590  
(SUB-CONTRACT ON NBS PROJECT 3150420)

This sub-contract is for a detailed literature search for the desired data and the evaluation and appraisal of the acquired data for the eight metals listed below. For these eight metals and the stable oxides of their major constituents, the following properties, if available, shall be reported for the temperature range and physical state noted in Table I:

specific heat	emissivity
thermal conductivity	Prandtl number
density	surface tension.
thermal diffusivity	

These data will be presented in both tabular and graphical forms, and where the literature search renders no data or the data are deemed to be in error, values shall be derived by interpolation and where feasible by extrapolation over the temperature ranges as noted in Table I by appropriate semi-theoretical techniques and empirical approximation methods. Error variances will be noted for all properties and materials over the designated temperature ranges. The eight metals to be considered in this investigation are:

aluminum - 6061-T6	titanium alloy - Al10-AT
aluminum alloy - 2219-T852	beryllium
aluminum alloy - 7075-T6	stainless steel - 304-A
inconel - X-750	stainless steel - 347.

During the current reporting period, progress is reported on this contract consisting of the literature survey and data compilation on thermophysical properties of the selected materials. The accomplishment reported herein is not for the complete quarter since this project was not activated until February 1, 1965. The materials covered in this quarter were the eight alloys specified above together with the oxides of their major constituents in the solid, liquid, and vapor phases.

Execution of the task for the thermophysical properties of selected materials has been organized and phased according to the following schedule:

<u>Period</u>	<u>Reporting Periods</u>	<u>Contemplated Task Coverage</u>
Feb. 1 to April 30	Feb. 1 to March 31	a) Search of TPRC files of all back literature per specified properties and materials b) Identification of unpublished material through personal contacts
May 1 to July 31	April 1 to June 30	a) Extraction and organization of information at hand b) Initiate analysis and extensions as packets of information are put together
Aug. 1 to Jan. 31, 1966	July 1 to Sept. 30 and Oct. 1 to Dec. 31	a) Complete extraction of remaining documents b) Devote time to analysis, correlation, and extension of data
	Final Report, Jan. 31, 1966	Reporting all results obtained



As of this reporting period the literature searching is somewhat ahead of schedule and is anticipated to be completed no later than April 15. The search covered the world's literature as early as 1920 for six of the eight properties listed and back to the mid 1940's for the density and surface tension. The result of the search has yielded nearly 1200 references of which over half have already been procured and nearly 300 are being ordered. The effort in current weeks is one of organization of the information at hand as to property and material covered so that a guide can be obtained, as early as possible, concerning the abundance or paucity of information relative to specific properties and materials.

The plans for the second quarter are for the organization of the information at hand and extraction of the data. It is hoped that data analysis and extensions may be initiated for certain selected groups of properties and materials.

Initiation of specific tables cannot be planned a priori since much will depend on what is uncovered in the literature search. Everything else being equal, priority will be given to the order indicated in private communications with the sponsors. It is anticipated that the various elements of the program will progress in parallel. Every effort shall be made during the first three months, in particular, to transmit all meaningful information to the project sponsors without waiting for formal reporting time. Inasmuch as the initiation of the specific tables cannot be planned, this task is not included in the summary tables. It may be reported, however, that the preliminary bibliography has been completed from the TPRC files, the literature search has been completed for all properties and all materials, and the literature procurement is now 60% completed.

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TABLE I

Property Item	Temperature Range	Phase	Material
Specific heat	0°R to M.Pt. and above	Solid; Liquid	Alloys; Elements
Thermal conductivity	0°R to M.Pt. and above	Solid; Liquid	Alloys; Elements
Density	0°R to M.Pt. and above	Solid; Liquid	Alloys; Elements; Molten Oxides
Thermal diffusivity	0°R to M.Pt. and above	Solid; Liquid	Alloys; Elements
Emissivity	0°R to M.Pt. and above	Solid; Liquid	Alloys; Elements; Oxides
Viscosity	M.Pt. and above	Liquid	Alloys; Elements; Oxides
Prandtl number	M.Pt. and above	Liquid	Alloys; Elements; Oxides
Surface tension	M.Pt. and above	Liquid	Alloys; Elements; Oxides

## 7.0 SUMMARY CHART OF DATA COMPILATION UNIT PROJECTS

TASK NUMBER	DATA COMPILATION TASK	ANTICIPATED STARTING DATE	DATE TASK WAS INITIATED										PUBLICATIONS (numbers refer to references listed in Section 9.0)	ESTIMATED COMPLETION DATE	TASK INACTIVE (date)	TASK COMPLETED (date)
			PRELIMINARY BIBLIOGRAPHY COMPILED FROM OUR FILES	LITERATURE SEARCH	LITERATURE PROCUREMENT (as listed in bibliography)	BIBLIOGRAPHY COMPILED	DATA EXTRACTION AND ORGANIZATION	DATA ANALYSIS AND CORRELATION	DATA PREDICTIONS AND EXTENSIONS	REPORT PREPARATION	REPORT IN EDITORIAL REVIEW OR IN PRESS (date)	PROPERTY DIAGRAMS (numbers refer to diagrams listed in Section 8.0)				
NBS PROJECT 3150420 (NASA - SNPO, NASA Order R-45)																
1 A	Saturation and Fixed Point Properties of Cryogenic Fluids		1/62			100%	100%	80%	10%			3/65	18 (in press)	11/66		
2 A	Thermodynamic Properties of Argon (also see item 4 C)		1/61			100%	100%	90%	75%	60%			13, 14	9/65		
3 A	Viscosity of Cryogenic Fluids (also see item 12 C)	6/65														
4 A	Thermal Conductivity of Cryogenic Fluids (also see item 13 C)	9/65											6			
5 A	Physical Equilibria and Related Properties of Binary Systems, including Hydrogen	6/65														
6 A	Physical Equilibria and Related Properties of Binary Systems, including Fluorine	6/65														
7 A	Dielectric Constant of Cryogenic Fluids (also see item 14 C)	1/66	4/62			100%	100%	100%	5%	5%			12		4/64	
8 A	Electrical Resistivity of Pure Metals	6/66														
9 A	Thermodynamic Properties of Fluorine (also see item 5 C)	12/66					90%						5			
10 A	Thermodynamic Properties of Air	1/67											4		10/62	
11 A	Surface Tension of Cryogenic Fluids (also see item 15 C)	11/65														
12 A	Thermodynamic Properties of normal and para Hydrogen (also see item 1 B)		1/64	1/64	90%	85%	90%	70%					19†	12/66		
13 A	Thermodynamic Properties of Neon					100%	100%	100%	100%	100%		D-44, 48, 49	3, 7, 16, 17			2/65
NBS PROJECT 3150421 (NBS-NSRDS)																
1 B	Thermodynamic Properties of normal and para Hydrogen (also see item 12 A)		1/64	1/64	90%	85%	90%	70%					19†	12/66		
NBS PROJECT 3150422 (NASA - MSFC, Government Order H-76197)																
1 C	Thermodynamic Properties of Oxygen		*			100%	100%	100%	50%	50%			D-45†	2†, 10†, 15†	8/65	
2 C	Thermodynamic Properties of Nitrogen	6/66														
3 C	Thermodynamic Properties of Helium	10/66											1†			
4 C	Thermodynamic Properties of Argon (also see item 2 A)		*			100%	100%	90%	75%	60%			13†, 14†	9/65		
5 C	Thermodynamic Properties of Fluorine (also see item 9 A)	12/66					90%						5†			
6 C	Binary Mixtures of O <sub>2</sub> and N <sub>2</sub>	2/65	1/65	80%	70%			30%								
7 C	Binary Mixtures of A and N <sub>2</sub>	2/65	1/65	80%	70%			30%								
8 C	Binary Mixtures of O <sub>2</sub> and He	6/66														
9 C	Binary Mixtures of N <sub>2</sub> and He	6/66														
10 C	Binary Mixtures of H <sub>2</sub> and He	6/66														
11 C	Binary Mixtures of F <sub>2</sub> and He	5/66														
12 C	Viscosity of O <sub>2</sub> , N <sub>2</sub> , He, A, and F <sub>2</sub> (also see item 1 A)	6/65														
13 C	Thermal Conductivity of O <sub>2</sub> , N <sub>2</sub> , He, A, and F <sub>2</sub> (also see item 1 A)	9/65											6†			
14 C	Dielectric Constant of O <sub>2</sub> , N <sub>2</sub> , He, A, and F <sub>2</sub> (also see item 7 A)	1/66	*			100%	100%	100%	5%	5%			1†		4/64	
15 C	Surface Tension of O <sub>2</sub> , N <sub>2</sub> , He, A, and F <sub>2</sub>	11/65	*										4†		10/65	
16 C	Electrical Properties of O <sub>2</sub> , N <sub>2</sub> , He, A, and F <sub>2</sub>	7/65														

\*task initiated previously with funding from another source

† publications from other projects

# 8.0 THERMODYNAMIC PROPERTY CHARTS\*

Fluid	Number†	Coordinates	Range	Data Source††	Date Issued
Helium	D-3	T-S	20 to 300°K, 0.1 to 100 atm	[1]	June 1961
	D-52	T-S	15 to 300°K, 0.1 to 100 atm	NBS Tech Note 154	Jan. 1964
	D-53	T-S	3 to 25°K, 0.5 to 100 atm	"	"
	D-54	H-S	3 to 25°K, 1.0 to 100 atm	"	"
	D-13	P-Z	20 to 300°K, 1.0 to 100 atm	[1]	Feb. 1961
Parahydrogen (British units)	D-20A*	T-S	20 to 100°K, 1.0 to 340 atm	NBS Tech Note 130	Dec. 1961
	D-21A	T-S	80 to 300°K, 1.0 to 100 atm	"	"
	D-22A*	H-S	20 to 60°K, 1.0 to 340 atm	"	"
	D-20B*	T-S	36 to 180°R, 1.0 to 5000 psia	"	"
	D-21B	T-S	140 to 540°R, 1.0 to 1500 psia	"	"
	D-22B*	H-S	36 to 112°R, 1.0 to 5000 psia	"	"
	D-20	T-S	14 to 100°K, 0.1 to 340 atm	NBS Monograph 94	(1965) (in press)
	D-22	H-S	16 to 64°K, 0.3 to 340 atm	"	"
	D-14	P-Z	16 to 300°K, .08 to 800 atm	WADD TR 60-56**	Jan. 1961
	D-4	T-S	0 to 150°K, 0.6 to 300 atm	NBS - RP 1932	1948
Normal Hydrogen	D-5	T-S	130 to 300°K, 0.8 to 600 atm	"	"
	D-28	T-S	280 to 600°K, 1.0 to 1200 atm	"	"
	D-48-R	T-S	60 to 300°K, 0.1 to 200 atm	[16]	Mar. 1965
	D-49-R	T-S	25 to 80°K, 0.1 to 200 atm	[16]	"
Neon	D-44	P-Z	30 to 300°K, 1.0 to 200 atm	[3]	Sept. 1962
	D-23	T-S	65 to 300°K, 0.1 to 200 atm	NBS Tech Note 129	Jan. 1963
	D-16	P-Z	90 to 300°K, 1.0 to 500 atm	WADD TR 60-56**	Nov. 1960
	D-17	P-Z	90 to 300°K, 300 to 3000 atm	"	"
	D-45	T-S	54 to 100°K, sat. liquid to 200 atm (liquid phase only)	NBS Report 7671	Jan. 1963
Air	D-18A	P-Z	90 to 300°K, 1.0 to 600 atm	WADD TR 60-56**	Oct. 1960
	D-18B	T-Z	75 to 300°K, 1.0 to 1000 atm	"	"
Carbon Monoxide	D-51	T-S	70 to 300°K, 0.1 to 300 atm	[11]	Sept. 1963
	D-50	P-Z	100 to 300°K, 1.0 to 300 atm	[11]	"

\* Unless otherwise noted, charts are in metric units.

† May be ordered from the Cryogenic Data Center, NBS, Boulder by this number. Both 8-1/2 x 11" and 17" x 22" sizes available at 10¢ and 25¢ each, respectively.

\* Superseded by D-20 or D-22

\*\* "A Compendium of the Properties of Materials at Low Temperatures (Phase II)", WADD Technical Report 60-56, Part IV R. B. Stewart and V. J. Johnson, General Editors (Dec. 1961).

†† Numbers in brackets refer to references listed in Section 9.0.

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\* Copies may be ordered from the Cryogenic Data Center, NBS, Boulder, Colorado.